Evaluation of the
“Dissolved Oxygen TMDL Basin Plan Amendment Staff Report”

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Report Scope and Structure

This report is in response to the request of Mr. Mark Gowdy of the CV RWQCB for evaluation of the proposed *"Dissolved Oxygen TMDL Basin Plan Amendment Staff Report"* (*Staff Report*) for the Stockton Deep Water Ship Channel (DWSC). Specifically, the request was for *"comments on whether the following components of the report are adequately based on valid and reasonable interpretations of available published studies and general scientific principals* [sic]*:*
1. Identification of main factors and the mechanisms by which they contribute to the impairment
2. Determination of the loading capacity as a function of flow and temperature
3. Determination of the margin of safety
4. Apportioning of oxygen demand loading capacity (less margin of safety) equally between the load-related and two non-load related contributing factors
5. Allocation of oxygen demand loading capacity to various point and non-point sources of oxygen demanding substances (30%/70%)
6. Implementation plan for continued study of causes in lieu of developing detailed wasteload and load allocations based on existing science."

For several years, incidents of low DO concentrations have been observed in DWSC. These incidents frequently violated water quality objective, i.e., 6 mg/L from September to November and 5 mg/L during the rest of the year. Although most incidents of low DO occurred between June and October, some violations were observed in every month during last twenty years. In some months, the ratio of low DO measurements to total hourly measurements exceeded 90%. In addition, the severity of low DO incidents is positively correlated with their frequency, further aggravating the water quality problem.

In essence, the question put forward to me is whether the findings and proposed solutions contained in the *Staff Report* can be justified scientifically. The review of the associated voluminous studies on the low DO problem in DWSC is beyond the scope of my report. The findings of these studies were previously reviewed by many parties. For the purpose of my report, it is assumed that these findings are factual and are taken as such to the extent that they provide pertinent information for evaluation of scientific validity of the *Staff Report*.

Science concerns itself with examination of testable hypotheses through observations, experiments and models. Thus, it cannot deal with answers or actions that are based on preferences, opinions or judgements. The latter can be perfectly reasonable but are outside the purview of science. I am making this statement to underscore the basis, methods and limitations of my report. The report reviews each of the six issues stated above and for each of them provides my opinion as to the **scientific** basis for the proposed decisions.

1. Main Factors and Mechanisms

The *Staff Report* identified three main factors contributing to low DO concentrations in the DWSC: load of oxygen-consuming substances entering the channel, low net flows through the channel, and the existence of the DWSC itself. Oxygen-consuming substances were further sub-categorized depending on their source. Some of these substances originate as the effluent from Stockton RWCF, primarily as ammonia with an additional contribution from carbonaceous BOD. The San Joaquin River (SJR) was identified as the other source of oxygen-consuming substances, primarily as algae. The growth of algae upstream of DWSC is a consequence of nutrient discharge in the SJR watershed associated with agricultural activities.

One important contribution to oxygen-consuming substances is due to algae grown in the DWSC. The *Synthesis* report (Lee and Jones-Lee, 2003) stated (p. ix) that *"algal load from growth in the DWSC was found at times to be equal to that from the upstream sources."* Although it can be argued that **on average**, algae growing in the DWSC contribute enough oxygen through photosynthesis to balance the consumption caused by their respiration and decay, localized oxygen consumption by algae and their decay products can exceed their oxygen production. Since DO depletion is a highly dynamic process and potential contributions from algal growth in the DWSC are significant, these processes should be taken into account especially as they may contribute to DO depletion in lower strata of the DWSC (*Synthesis*, p. 34; Van Nieuwenhuyse, 2002, p. 20). Like algal growth upstream in the SJR, the growth in the DWSC is made possible by the excess of nutrients and is limited by light (*Synthesis* pp. viii & 36).

The contributions from both sources and mechanisms by which they exert oxygen demand have been shown and are scientifically incontestable. Ammonia discharged to the DWSC undergoes oxidation by nitrifying microorganisms. During this process, oxygen is consumed (at approx. 4.3 lb per lb of nitrogen). Similarly, algal respiratory processes and microbial decomposition of dead algae exert oxygen demand. If the demand due to nitrification, algal respiration and decay, and possibly from other minor sources is not met by oxygen supply from reaeration, incoming flow, and production by algal photosynthesis, oxygen dissolved in water is consumed and its concentration decreases. Thus, the presence of oxygen-demanding substances is a **necessary** but **not always a sufficient** condition for a low DO incidence.

The *Staff Report* further claimed that two additional factors contribute to low DO incidents: *"the DWSC geometry"* and *"reduced flow through the DWSC"*. The report stated that *"DWSC geometry"* reduces the loading capacity of the DWSC for oxygen-demanding substances by *"by (i) reducing the efficiency of natural re-aeration mechanisms and (ii) magnifying the effect of oxygen demanding reactions"* while the *"reduced flow through the DWSC further reduces the loading capacity by increasing the residence time for oxygen demanding reactions in the DWSC."* These two factors are closely related as they both ultimately contribute to the same physical phenomenon of low net velocity in the channel. Although the actual flow in the DWSC is strongly influenced by the tides, the net velocity can be, at times, small. The cross-section area of the DWSC is much larger than that of the SJR upstream. Thus, for a given flow the net average velocity is smaller in the DWSC compared with the upstream reach. Obviously, any reduction of the flow upstream, also causes a decline of the flow velocity. Thus, there is no doubt that if the channel geometry or upstream flows were different, the velocity of water in the DWSC would also be different.

The relation of channel geometry and incoming flow rates to water velocity is very important for the evolution of DO concentration in the channel. The mechanisms by which water velocity influences the DO profile is well understood and scientifically sound although quantification of the effect could still be improved. First, low net velocity (or low net flow rates for a given cross-section geometry) causes long detention times of water and its contents in the channel. The *Synthesis* (p. vi) reported that the detention time in the channel can vary from 4 days at high flows to 30 days at low flows. Long detention times in the channel allow oxygen-consuming processes (nitrification and algal decay) to develop. In addition, lower flow velocities impair oxygen transfer from air to water, exacerbating DO depletion in the channel. Empirically, the effects of net flow rates on minimum DO concentrations have been well demonstrated as shown in Fig. 4-3 of the *Staff Report*. It appears, that above a threshold net flow of approximately 2500 cfs, no significant DO depletion was observed. The data in Fig. 4-3 should be replotted, if possible, as percent DO saturation rather than DO concentration to take into account variable temperature effects. Additionally, water quality models (Chen and Tsai, 2001) also demonstrated that the existence of the DWSC and reduced flows constitute again **necessary** but not sufficient conditions for DO depletion.

Conclusion #1
Although none of the three factors listed in the *Staff Report* is singularly responsible for oxygen deficiency, the **combination** of oxygen-consuming loads and low net velocity in the channel is responsible for the problem. In turn, the velocity is a direct function of channel geometry and water flow upstream of the channel.

2. Determination of the loading capacity

The objective of the *Staff Report* was to develop a TMDL for low dissolved oxygen in the DWSC. It was a difficult task because DO and DO deficit are not pollutants *per se* but rather symptoms of pollution originating from a variety of sources. The development of the TMDL for such symptoms appears to be a result of a regulatory straightjacket that requires a formulation of a load (expressed in pounds per day).

The *Staff Report* proposed a quantitative TMDL for dissolved oxygen for the DWSC on the basis of DO loading capacity also developed in the report. On p. 34 of the *Staff Report*, loading capacity was defined as the *"allowable rate of oxygen demand at the point of lowest DO concentration in the DWSC, such that the Basin Plan DO objectives are maintained."* The loading capacity was further expressed by Eq. 4-1 as a product of maximum allowable oxygen deficit and the net daily flow through the DWSC. The deficit was defined as the difference between DO saturation concentration and the established DO objective (5 or 6 mg/L). As the value of the DO deficit is relatively constant, being only a function of water temperature and the regulatory DO objective, the flow through the DWSC is a major controlling factor behind the loading capacity. The *Staff Report* (p. 35) explicitly stated that the temperature *"will not be a factor that is allocated responsibility for mitigating the DO impairment."* Therefore, the loading capacity is essentially proportional to the net DWSC flow.

From a **scientific** point of view, the development of the loading capacity in the form presented by Eq. 4-1 would make sense if dissolved oxygen was a conservative substance entering the DWSC. However, dissolved oxygen is consumed by microbial processes, generated by algae, transferred from the atmosphere, and imported and exported with the flow. Low DO concentration in the channel is a result of an imbalance between the **overall rate** of oxygen consumption and export, and the **rate** of oxygen supply and generation. In this sense, the verbal definition on p. 34 as the "*allowable rate of oxygen demand*" is much better. Although both the **rates** of oxygen consumption, generation and supply are expressed in the same units (lb/day) as the proposed loading capacity, they are not equivalent. The rates describe intensities of specific physical, chemical and biological processes while the proposed loading capacity is an abstract construct.

This limitation of the loading capacity and the TMDL developed on its basis was acknowledged on p. 41 of the *Staff Report* where it stated that due to this deficiency *"detailed load limitations or requirements for other mitigation measures are not possible at this time."* It appears that the loading capacity and the TMDL were developed as a tool to allocate responsibility for DO depletion to various parties, and in this context the abstract construct may serve its purpose.

Conclusion #2
The loading capacity expressed by Eq. 4-1 is essentially proportional to the net flow rate and although expressed in the units of lb/day, it is a regulatory tool rather than a physically meaningful quantity.

3. Margin of Safety (MOS)

The *Staff Report* proposed to establish a 40% margin of safety. This is an important issue because MOS adoption in the proposed form reduced the TMDL available for allocations to 60% of the established value of loading capacity. The proposed MOS value of 40% is composed of two equal parts. One part (20%) is supposed to reflect *"technical uncertainty surrounding the allocation of wasteloads and loads to sources of oxygen demanding substances and the assumptions regarding the extent to which the impact of non-load related factors can or will be mitigated."* This part of MOS was explicitly based on *"professional judgement"* and as such cannot be validated scientifically. However, I must point out that this part of MOS is supposed to account for lack of knowledge about the linkages between wasteloads and sources of oxygen demanding substances. As discussed in Section 2 of my report, the proposed TMDL does not address this complicated issue directly but merely establishes an allowable load of oxygen deficit, an arbitrarily defined quantity. The uncertainties of how to translate an allocation of oxygen deficit to specific oxygen demanding sources are real; the question is whether they should be addressed at the DO TMDL level or when the loads of specific substances are established based on studies proposed in Section 4.6.1 of the *Staff Report*.

The remaining 20% of MOS reflects the uncertainty of flow estimates in the SJR upstream of DWSC. Flow estimates are based on measurements of flow velocities with an ultrasonic velocity meter (UVM). It was implicitly assumed in the *Staff Report* that this single point measurement adequately represents overall flow rate in the SJR at this location. Furthermore, the *Staff Report* stated (p. 37) that the accuracy of *" the net daily flows determined from measurements at this UVM is believed to be in the range of 20 to 40 cfs."* Based on the stated accuracy, which I assume is true, and a nominal flow value of 200 cfs, the additional MOS was determined at 20% for all flow values. The nominal value of 200 cfs is very low in comparison with the range of flows recorded at the UVM location. Thus, it seems unjustified to use the blanket MOS contribution of 20% for all flows. For a flow of 1500 cfs (still in the low range of recorded values), this MOS contribution due to velocity measurements would translate to 300 cfs, higher than the specified nominal flow. While it is true that DO depletions are most severe at low flows and therefore MOS for those flows should be appropriately large, it is my opinion that expressing MOS contribution as a fixed percent value is not scientifically justified. Since the accuracy of the UVM was stated as relatively constant (20 to 40 cfs) compared with more that ten-fold flow variations, it seems more appropriate to express the MOS contribution also as a fixed value.

Conclusion #3

The proposed MOS value of 40% is composed of two parts. The first part of 20% is based on *"professional judgement"* and, while it may be appropriate, it was not scientifically tested or validated. The second part, also of 20%, seems to overestimate flow inaccuracies at higher flows; it should be expressed as a fixed value related to the stated inaccuracies of velocity measurements.

4. Apportioning of oxygen demand loading capacity (less margin of safety) equally between the load-related and two non-load related contributing factors

The *Staff Report* (Section 4.5) allocated the TMDL equally to three contributing factors, i.e., load of oxygen-consuming substances, DWSC geometry, and reduced SJR flows. Furthermore the allocation of 1/3 of TMDL to oxygen-consuming load is further divided: 30% due to discharges from the Stockton RWCF and 70% due to *"algae load"* originating upstream.

While the allocation of the load-related TMDL portion (one-third of the total) between Stockton and upstream sources can be justified scientifically (see Section 5 of my report), no such justification can be provided for the primary equal allocation between load, channel geometry, and reduced flows. As stated in Conclusion #1, the combination of all three factors is responsible for DO depletion in the DWSC, there is no **scientific** basis for equal allocation of TMDL. Such allocation, or another split, may be justified in social or political terms if all three factors are recognized as controllable within the meaning of the CVRWQCB Controllable Factors Policy. This assessment was recognized in the *Staff Report* (p. 2 and 9) where the primary TMDL allocation is based on "*equitability*". This criterion was further emphasized in Section 5 of the *Staff Report*. Similarly, the *Draft Strawman Source and Linkage Analysis* (April 2002) explicitly linked the benefits of the DWSC *"presence"* and the *"removal and use of San Joaquin River water"* to the responsibility for low DO conditions.

Conclusion #4
The allocation TMDL **equally** to three contributing factors may be justified on *"equitability"* or other social, political or economic basis. Scientific method cannot be applied to arrive at such precise quantitative division.

5. Allocation of oxygen demand loading capacity to various point and non-point sources of oxygen demanding substances (30%/70%)

Although the primary division of TMDL into three equal parts may not be accomplished through scientific methods, further sub-divisions of the load-related portion (whatever it may be) can be. The 30-70 allocation of a portion of TMDL between Stockton RWCF and upstream loads was based on measurements of ultimate BOD loads from these two sources as measured over a few years. While the loads varied considerably depending on flows, concentrations and other factors, the 30-70 split reflects a general trend in the data. If a **fixed** percentage-based allocation between the two sources is desired, the proposed 30-70 split seems to be consistent with available scientific data. The remaining uncertainty about this allocation is related to poor knowledge of how the ultimate BOD loads (and particularly nitrogenous BOD) translate to actual DO depletion (see Lehman, 2002, pp. 2-3). When better knowledge is available, the proposed allocation should be reviewed.

Conclusion #5
Within available scientific knowledge, the allocation of a load-related TMDL portion between Stockton RWCF (30%) and to sources of algae and/or precursors in the watershed (70%) is generally consistent with available data.

6. Implementation plan for continued study of causes in lieu of developing detailed wasteload and load allocations based on existing science.

The *Staff Report* (pp. 42 ff) proposed a phased TMDL and a phased implementation approach. The approach would include a series of studies to understand *"the sources of oxygen demanding substances in the watershed and their linkage to the DO impairment"* and to *"evaluate the performance and cost of the most practical and effective mitigation measures."*

The question posed to me requires an assessment of the **value** of further studies as opposed to the **value** of a decision based on current understanding. This question again cannot be answered in scientific terms as it involves a value judgement. However, the question and the answer can be placed in the context of current scientific uncertainty and the objectives of further studies. It appears to me that the objectives of further studies are two-fold. First, they are to provide a scientific basis to reduces existing uncertainties between sources of oxygen-demanding substances and oxygen depletion in the DWSC. Second, they are to assess the efficacy and costs of any remedial actions (such as artificial aeration, nutrient load reduction, etc.).

The goal of reducing scientific uncertainty is laudable. However, such reduction (and the costs of achieving it) must be compared with another uncertainty that is inherently embedded in the decision-making process and cannot be reduced by further studies. As described in the answer to Question 4, basic apportioning of the TMDL among three listed factors is beyond the reach of science. It is ultimately a responsibility of the Regional Board to reach a decision based on the judgement of Board members that cannot be abrogated to a computer. Similarly, any fixed (or even dynamic) sub-allocation of load-related TMDL portion between individual sources must, by necessity, only approximate actual, day-to-day contribution from each source to DO depletion. After **any** decision, a substantial discrepancy between actual contributions and their regulatory allocations will remain due to seasonal changes, natural flow variabilities, temperature variations and many other factors. Given the very long history of the problem and its complexity, it is my **opinion** that further studies, desirable as they may be to reduce one kind of uncertainty, will not diminish the burden on the Board to make the ultimate "equitable" decision.

Once a decision is arrived at, and in my opinion the sooner the better, the scope of mitigation measures will be established. Then it will be very desirable to evaluate different alternatives, their costs and benefits.

Conclusion #6

Scientifically irreducible uncertainty of any ultimate decision regarding DWSC will remain significant. For this reason, further "source and linkage" studies will contribute marginally to the establishment of TMDL. Such studies and those of possible remediation measures may have a value once the basic TMDL decision is made to find cost-effective, equitable and feasible solutions of oxygen depletion in the DWSC.

References

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